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THE STATUS AND QUALITY OF RADIATION MEASUREMENTS FOR AIR

by

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FOREWORD

Protection of the environment requires effective regulatory actions which are based on sound technical and scientific information. This information must include the quantitative description and linking of pollutant sources, transport mechanisms, interaction, and resulting effects on man and his environment. Because of the complexities involved, assessment of specific pollutants in the environment requires a total systems approach which transcends the media of air, water, and land. The Environmental Monitoring and Support Laboratory-Las Vegas contributes to the formation and enhancement of a sound integrated monitoring data base through multidisciplinary, multimedia programs designed to:

- develop and optimize systems and strategies for monitoring pollutants and their impact on the environment
- demonstrate new monitoring systems and technologies by applying them to fulfill special monitoring needs of the Agency's operating programs

This summary report, "The Status and Quality of Radiation Measurements for Air," should be useful in evaluating the quality of environmental radiation data. The data contained in this report should be of value to the EPA, other Federal agencies, State agencies, and private laboratories. For further information on the data contained in this publication contact the Quality Assurance Branch, Environmental Monitoring and Support Laboratory-Las Vegas, Nevada.

George B. Morgan
Director
Environmental Monitoring and Support Laboratory
Las Vegas

ABSTRACT

As part of the radiation quality assurance program conducted by the U.S. Environmental Protection Agency, calibrated radionuclide solutions are distributed to participating laboratories for instrument calibration and yield determinations. Laboratory performance studies involving the analysis of radionuclides in environmental media are also conducted.

A summary is given of the results of the air filter cross-check program for 1973-1975. Examination of these results indicate that gross alpha is the least difficult (86 percent within the control limits for accuracy) and gross beta is the most difficult (39 percent within the control limits for accuracy) for the laboratories to analyze.

CONTENTS

	Page
Foreword	iii
Abstract	iv
List of Figures and Tables	vi
Introduction	1
Methods and Procedures	4
Preparation of Air Filters	4
Analysis by Participants	5
Results and Discussion	10
Summary	27
APPENDIX. Statistical Calculations	29

LIST OF FIGURES

Number		Page
1	Computer report	6
2	Control chart	8
3	Histogram of laboratory averages reported for strontium-90. .	15
4	Histogram of laboratory averages reported for cesium-137. . .	18
5	Histogram of laboratory averages reported for gross alpha . .	21
6	Histogram of laboratory averages reported for gross beta. . .	24

LIST OF TABLES

1	Summary of cross-check programs	3
2	Summary of air filter data for 1973-1975.	12
3	Summary of laboratory performance, 1973-1975 laboratory intercomparison studies - air filters .	28

INTRODUCTION

Environmental radiation measurements are made routinely by Federal, State, local, and private agencies. The data obtained from these measurements are utilized by the U.S. Environmental Protection Agency (EPA) and other agencies for such purposes as estimating dose and health effects, establishing standards and guides, and conducting regulatory activities. Therefore, it is essential that the precision and accuracy of the data be assured so that policy decisions concerning environmental quality are based on valid and comparable data.

The radiation quality assurance program of the EPA is designed to encourage the development and implementation of quality control procedures at all levels of sample collection and analysis, and data processing and reporting. As an integral part of the EPA's program, the Quality Assurance Branch of the Environmental Monitoring and Support Laboratory-Las Vegas (EMSL-LV) distributes calibrated radionuclide solutions for instrument calibration and chemical yield determinations, develops and tests analytical procedures for possible use as EPA-approved laboratory methods, and conducts a number of laboratory performance studies involving the analysis of radionuclides in environmental media.

The Laboratory Intercomparison Studies Program (performance studies) enables participating laboratories to maintain checks on their analyses and assists them in documenting the validity of their data. In addition, this program enables the EPA to obtain an overall estimate of the precision and accuracy of environmental radiation measurements, and the precision and accuracy of laboratory radioassay procedures for environmental samples.

Performance studies currently in progress involve samples of most environmental media and include milk, air, water, soil, diet, urine, and noble gases. Table 1 is a summary of these programs. Participants include some nuclear facilities and State, Federal and international laboratories. Because of the large and growing number of participants and the continuing nature of the programs, sufficient data are generated to permit periodic assessment of the quality of environmental data.

Participating laboratories perform analyses on the cross-check samples and return their data to the Quality Assurance Branch for statistical evaluation. Comparisons are made between laboratories and within an individual laboratory for accuracy and precision. A computer report and an updated performance chart are returned to each participant. This enables each laboratory to document the precision and accuracy of its radiation data, to identify

instrumental and procedural problems, and to compare performance with other laboratories.

A preliminary report on the laboratory performance studies conducted for air filters is presented on the following pages.

TABLE 1. SUMMARY OF CROSS-CHECK PROGRAMS*

Sample	Analysis	Activity Per Isotope	Quantity Supplied	Preservative	Distribution	Time for Analysis & Report
Milk	^{89}Sr, ^{90}Sr, ^{131}I, ^{137}Cs, ^{140}Ba, K	< 200 pCi/liter	∿ 4 liters	Formalin	Bimonthly	6 weeks
Water						
Gross α, β*	Gross α, β	< 100 pCi/liter	∿ 4 liters	0.5N HNO_3	Bimonthly	4 weeks
Gamma	^{60}Co, ^{106}Ru, ^{134}Cs, ^{137}Cs, ^{51}Cr, ^{65}Zn	< 500 pCi/liter	∿ 4 liters	0.5N HNO_3	Bimonthly	4 weeks
^{3}H	^{3}H	< 3500 pCi/liter	∿ 50 ml	none	Bimonthly	4 weeks
^{239}Pu*	^{239}Pu	< 10 pCi/liter	∿ 4 liters	0.5N HNO_3	Semiannually	8 weeks
Radium	^{226}Ra, ^{228}Ra	< 20 pCi/liter	∿ 4 liters	0.5N HNO_3	Quarterly	6 weeks
Air						
Gross α, β*	α, β, ^{90}Sr, ^{137}Cs	< 200 pCi/sample	3 - 2"-diam.† air filters	none	Quarterly	6 weeks
^{239}Pu*	^{239}Pu	< 2 pCi/sample	3 - 2"-diam.† air filters	none	Quarterly	6 weeks
Soil*	^{238}Pu, ^{239}Pu ^{228}Th, ^{230}Th, ^{232}Th	< 50 pCi/sample	∿ 35 grams	none	Semiannually	8 weeks
Diet	^{89}Sr, ^{90}Sr, ^{131}I, ^{137}Cs, ^{140}Ba, K	< 200 pCi/kg	2 - 4-liter samples	Formalin	Quarterly	8 weeks
Urine	^{3}H	< 3500 pCi/liter	∿ 50 ml	Formalin	Quarterly	4 weeks
Gas	^{85}Kr	< 20 pCi/ml	10 liters	none	Quarterly	6 weeks

*Laboratories are required to have the necessary licenses before receiving these samples.

†Metric equivalent = 50.8 millimeters

METHODS AND PROCEDURES

Glass fiber filters containing known amounts of specific radionuclides are prepared and distributed to a number of Federal, State and private laboratories. These samples are designed to test the ability of participating laboratories to analyze air filters for strontium-90, cesium-137, and gross alpha and gross beta radioactivities. Eight air filter intercomparison studies were conducted during the period July 1973 - December 1975.

Three 2-inch diameter* (or 4-inch diameter upon request) simulated air filters containing known amounts of radionuclides were sent to each participant. The filters were prepared to represent simulated air filter samples. The radionuclides and the concentration ranges are as follows:

Isotope	Concentration Range
^{90}Sr	38-198 pCi/filter
^{137}Cs	25-1180 pCi/filter
gross alpha	38-196 pCi/filter
gross beta	101-735 pCi/filter

PREPARATION OF AIR FILTERS

Two- and 4-inch diameter glass fiber filters are sprayed with six coats of clear acrylic paint.† After the paint has dried, the filters are attached to individual stainless steel planchets using short strips of double-sided masking tape. The radioactive "spike" solution (after it has been checked for accuracy) is pipetted, in the form of tiny droplets, uniformly onto the filters. The filters are allowed to air dry and then dried overnight in a 110^{o} C drying oven. After cooling to room temperature, the filters are analyzed for radioactivity. If the calculated activities are within the 2σ-range counting statistics, the filters are packaged and shipped to the participating laboratories.

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*Metric equivalent = 50.8 millimeters

†Krylon #1301 Crystal Clear Acrylic Spray Coating

ANALYSIS BY PARTICIPANTS

Participating laboratories conduct three independent determinations for each radionuclide included in the particular cross-check sample and report the results to the Quality Assurance Branch. Control limits previously established by the Analytical Quality Control Service are used in analyzing the quality of the results obtained by these laboratories. These limits are based on the purpose for which the data are being obtained and on reasonable laboratory ability. Upon receipt of the reports from all participating laboratories, the data are analyzed using a computer. For each radionuclide, this analysis includes determination of the following parameters: the experimental average and standard deviation for each laboratory, the normalized range, the normalized deviation from the known and grand average, and the experimental sigma and the grand average of all laboratories. Examples of sample calculations to illustrate the computations performed by the computer are shown in the Appendix.

A report is generated containing the results of the data analysis and the data reported by all participating laboratories, listed according to laboratory identity code. Examples are shown in Figure 1. In addition, a control chart is generated for each radionuclide included in the sample (Figure 2). The control charts are updated each time a laboratory participates in a cross-check study, thus giving each laboratory a continuous record of its performance. A copy of the computer printout and a control chart for each radionuclide are mailed to each participant approximately 6 weeks following the report due date.

EMSL-LV TRITIUM IN URINE CROSS-CHECK PROGRAM --- SEPTEMBER 1974

09/20/74 SAMPLE - A 3H

KNOWN VALUE = 3273 PCI/L
EXPECTED LABORATORY PRECISION (1S, 1 DETERMINATION) = 357 PCI/L

LAB	RESULT	EXPERIMENTAL SIGMA	RNG ANLY ($\bar{R}$ + SR)	AVERAGE	NORMALIZED (GRAND AVG)	DEVIATION (KNOWN)
AN	NO DATA PROVIDED					
CF	3269					
CF	3522					
CF	3632	186.1	0.60	3474	0.9	1.0
CM	3261					
CM	3373					
CM	3362	61.7	0.19	3332	0.2	0.3
CO	NO DATA PROVIDED					
D	3060					
D	3060					
D	3240	103.9	0.30	3120	-0.8	-0.7
J	3255					
J	3247					
J	3294	25.1	0.08	3265	-0.1	-0.0
P	NO DATA PROVIDED					
Z	3240					
Z	3340					
Z	3190	76.4	0.25	3257	-0.2	-0.1

EXPERIMENTAL SIGMA (ALL LABS) = 149 GRAND AVERAGE = 3290

Figure 1. Computer report

Explanation of terms in Figure 1:

Title:	Program name, sample collection date, sample code letter, analysis type, known concentration of radionuclide, expected standard deviation of analysis - single determination.
Column 1:	Laboratory identification code (A, B, C, etc.).
Column 2:	Laboratory results (0-25 results listed down column).
Column 3:	One sigma (standard deviation) of the experimental results.
Column 4:	Normalized range value in "mean range + standard error of the range" ($\bar{R} + \sigma_R$) units for comparability. (See Statistical Techniques for Quality Control of Environmental Radioassay, AQCS Report Stat-1, November 1964, pages 4-8.) (SR = σ_R for printing purposes.)
Column 5:	Average value.
Column 6:	Normalized deviation from the grand average value of all laboratories expressed in σ_M units.
Column 7:	Normalized deviation from the known value expressed in σ_M units.
Bottom of Chart:	One sigma experimental error of all laboratories, and the grand average of all laboratories.

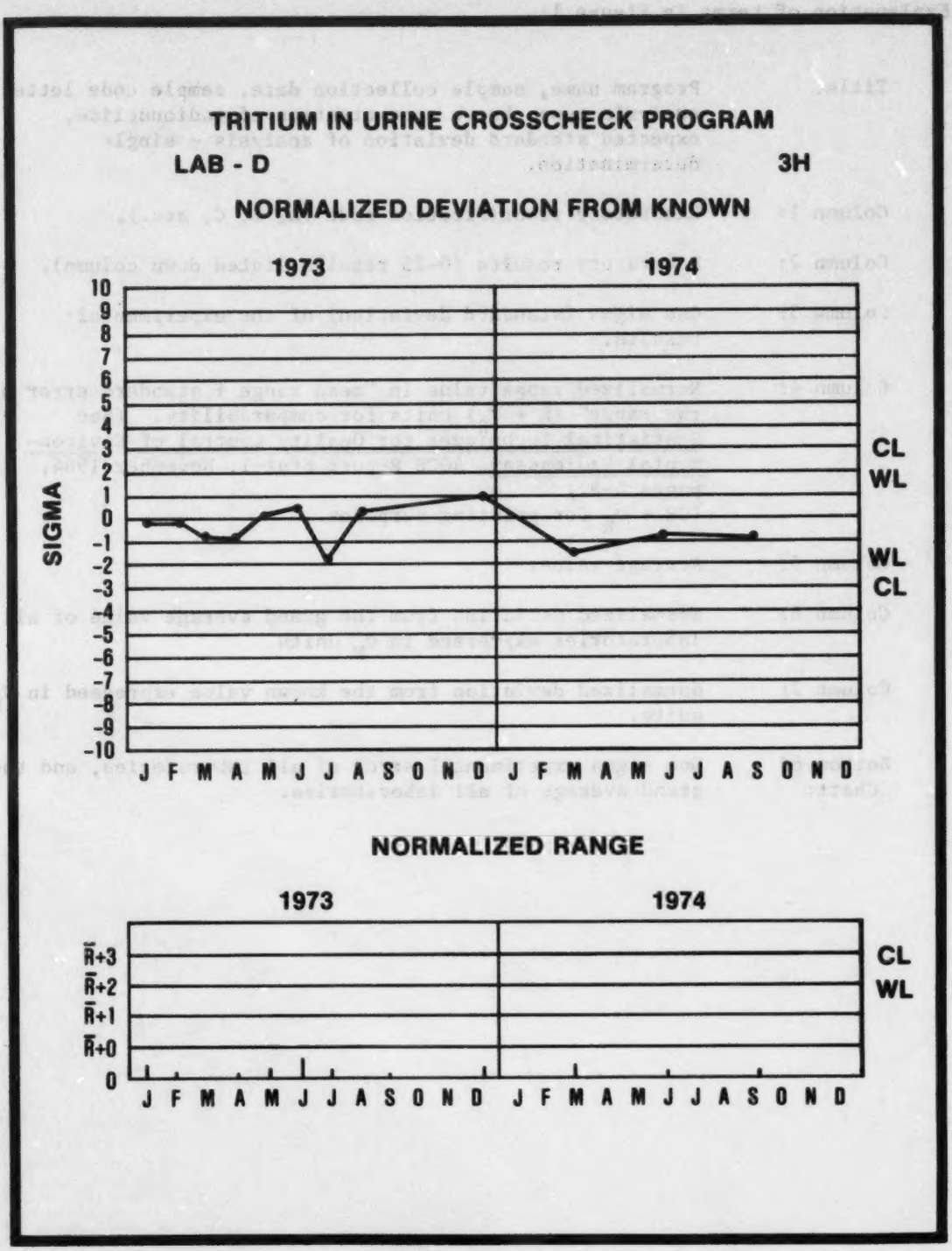

Figure 2. Control chart.

Explanation of terms used in the control chart (Figure 2):

Title:	Name of program, laboratory code letter, and type of analysis.
Upper Graph:	"Normalized deviation from known versus the month of analysis." [The 95.0% ($\mu \pm 2\sigma_M$) and the 99.7% ($\mu \pm 3\sigma_M$) confidence levels were chosen as the warning levels and control limits respectively.]
Lower Graph:	"Normalized range values ($\bar{R} + \sigma_R$) versus the month of analysis." [The 97.5% ($\bar{R} + 2\sigma_R$) and ∿100% ($\bar{R} + 3\sigma_R$) confidence levels were chosen as the warning levels and control limits respectively.]

RESULTS AND DISCUSSION

A laboratory is considered accurate, for our purposes, if its normalized deviation (known) is within ±3. A laboratory is considered precise if its range analysis ($\bar{R}$ + SR) is less than or equal to 4*.

The results of the air filter intercomparison studies are listed in Table 2 and shown in graph form in Figures 3-6. The $\bar{x}$ indicates the grand average and the μ denotes the known value. Each box represents an individual laboratory result.

STRONTIUM-90 (FIGURE 3)

All eight studies contained a strontium-90 spike. Forty-five percent of the laboratories reported results within the accuracy limits for the 3-year period. Eighty-eight percent reported replicate results with acceptable precision. In seven of the eight studies, the grand average value was less than the known value. This may be an indication that the analysis is biased low.

CESIUM-137 (FIGURE 4)

Cesium-137 was present in all eight studies. Fifty-five percent of the laboratories reported data within the acceptable limits while 96 percent of the laboratories possessed acceptable precision in their measurements. A comparison of the known and grand average values does not show any bias in the analysis.

GROSS ALPHA (FIGURE 5)

Seven of the eight studies included gross alpha activity. Eighty-six percent of the laboratories reported results within the control limits, and 100 percent met the precision requirements. In five of the seven studies the grand average values fell lower than the known values, possibly indicating a negative bias in the analysis.

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*Rosenstein, M., and A. S. Goldin, "Statistical Techniques for Quality Control of Radioassay," AQCS Report Stat-1, U.S. Department of Health, Education and Welfare, PHS, Nov 1964

GROSS BETA (FIGURE 6)

Gross beta activity was present in seven of the eight studies. Thirty-nine percent of the laboratories reported results within the control limits, and 97 percent reported replicate results with a precision meeting the requirements of the studies. In six of seven studies the grand average values were greater than the known values which would imply that the analysis is biased high.

TABLE 2. SUMMARY OF AIR FILTER DATA FOR 1973 - 1975

July 1973

	^{137}Cs	^{90}Sr	Gross Alpha	Gross Beta
N	9	5	---	---
μ(pCi/filter)	1180	90	---	---
$\bar{x}$(pCi/filter)	1172	81	---	---
σ(pCi/filter)	118	9	---	---
s(pCi/filter)	138	14	---	---
$(\sigma/\mu) \times 100(\%)$	10	10	---	---
$(s/\mu) \times 100(\%)$	12	16	---	---

May 1974

	^{137}Cs	^{90}Sr	Gross Alpha	Gross Beta
N	14	9	10	14
μ(pCi/filter)	46	47	48	194
$\bar{x}$(pCi/filter)	48	43	36	178
σ(pCi/filter)	5	5	12	10
s(pCi/filter)	9	9	6	19
$(\sigma/\mu) \times 100(\%)$	11	11	25	5
$(s/\mu) \times 100(\%)$	20	19	13	10

June 1974

	^{137}Cs	^{90}Sr	Gross Alpha	Gross Beta
N	18	8	15	20
μ(pCi/filter)	200	198	196	735
$\bar{x}$(pCi/filter)	199	187	177	770
σ(pCi/filter)	10	10	49	37
s(pCi/filter)	31	16	39	162
$(\sigma/\mu) \times 100(\%)$	5	5	25	5
$(s/\mu) \times 100(\%)$	16	8	20	22

N = sample size; μ = known value; $\bar{x}$ = grand average; σ = expected precision; and s = standard deviation.

(continued)

TABLE 2. (continued)

October 1974

	^{137}Cs	^{90}Sr	Gross Alpha	Gross Beta
N	24	15	29	27
μ(pCi/filter)	174	172	174	519
$\bar{x}$(pCi/filter)	184	164	171	296
σ(pCi/filter)	9	9	44	26
s(pCi/filter)	18	18	65	101
$(\sigma/\mu) \times 100(\%)$	5	5	25	5
$(s/\mu) \times 100(\%)$	10	10	37	19

February 1975

	^{137}Cs	^{90}Sr	Gross Alpha	Gross Beta
N	20	13	25	25
μ(pCi/filter)	151	160	150	470
$\bar{x}$(pCi/filter)	161	164	144	506
σ(pCi/filter)	8	8	37	24
s(pCi/filter)	19	24	42	70
$(\sigma/\mu) \times 100(\%)$	5	5	25	5
$(s/\mu) \times 100(\%)$	13	15	28	15

June 1975

	^{137}Cs	^{90}Sr	Gross Alpha	Gross Beta
N	29	17	32	27
μ(pCi/filter)	135	118	123	371
$\bar{x}$(pCi/filter)	142	112	128	389
σ(pCi/filter)	7	6	31	19
s(pCi/filter)	17	17	26	44
$(\sigma/\mu) \times 100(\%)$	5	5	25	5
$(s/\mu) \times 100(\%)$	13	14	21	12

N = sample size; μ = known value; $\bar{x}$ = grand average; σ = expected precision; and s = standard deviation.

(continued)

TABLE 2. (continued)

September 1975

	^{137}Cs	^{90}Sr	Gross Alpha	Gross Beta
N	27	11	36	31
μ(pCi/filter)	99	98	99	295
$\bar{x}$(pCi/filter)	96	91	89	304
σ(pCi/filter)	5	5	25	15
s(pCi/filter)	11	9	22	29
$(\sigma/\mu) \times 100(\%)$	5	5	25	5
$(s/\mu) \times 100(\%)$	11	9	22	10

December 1975

	^{137}Cs	^{90}Sr	Gross Alpha	Gross Beta
N	26	18	33	26
μ(pCi/filter)	25	38	38	101
$\bar{x}$(pCi/filter)	28	36	40	107
σ(pCi/filter)	5	2	10	5
s(pCi/filter)	7	7	7	8
$(\sigma/\mu) \times 100(\%)$	20	5	26	5
$(s/\mu) \times 100(\%)$	28	18	18	8

N = sample size; μ = known value; $\bar{x}$ = grand average; σ = expected precision; and s = standard deviation.

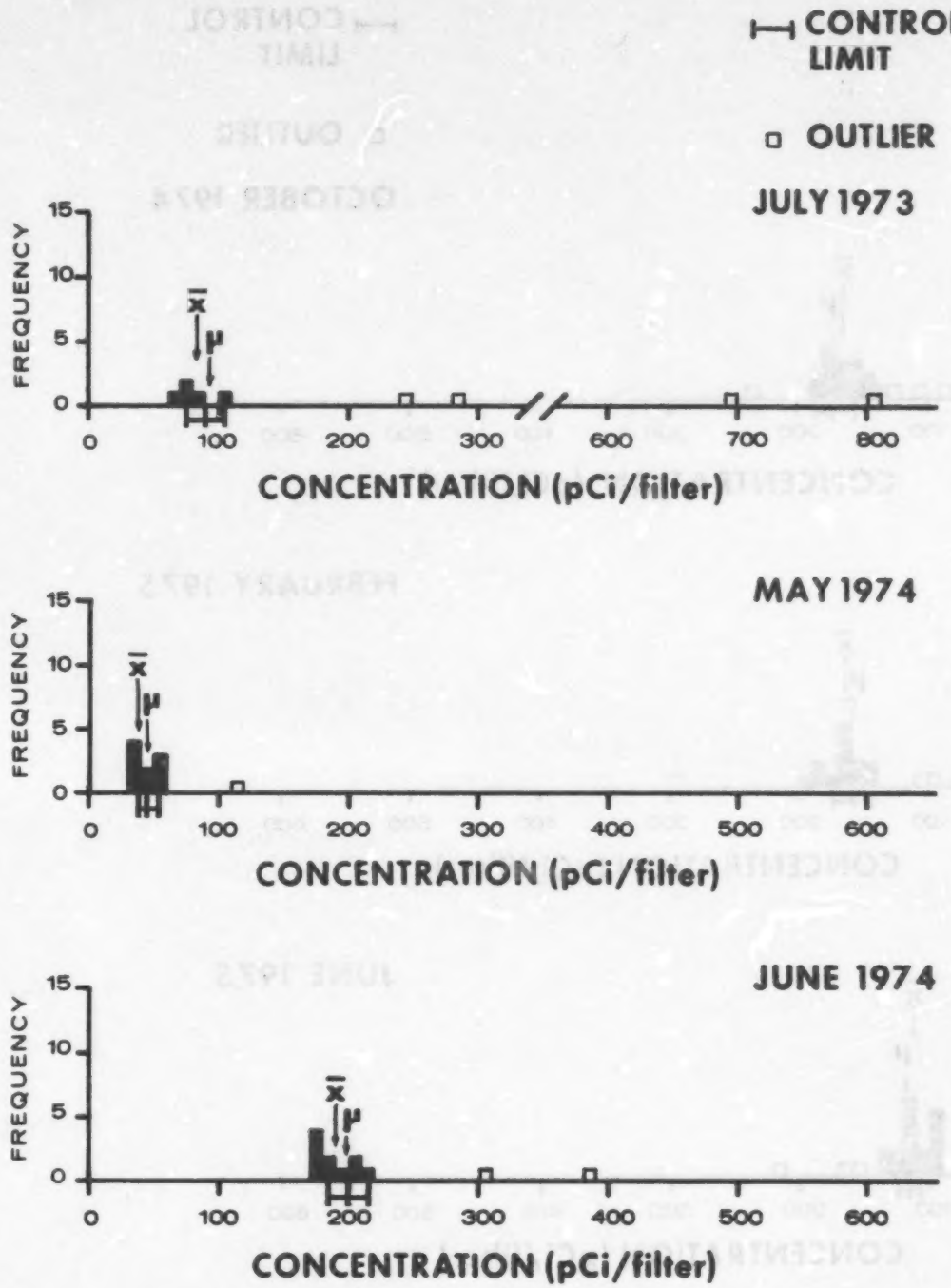
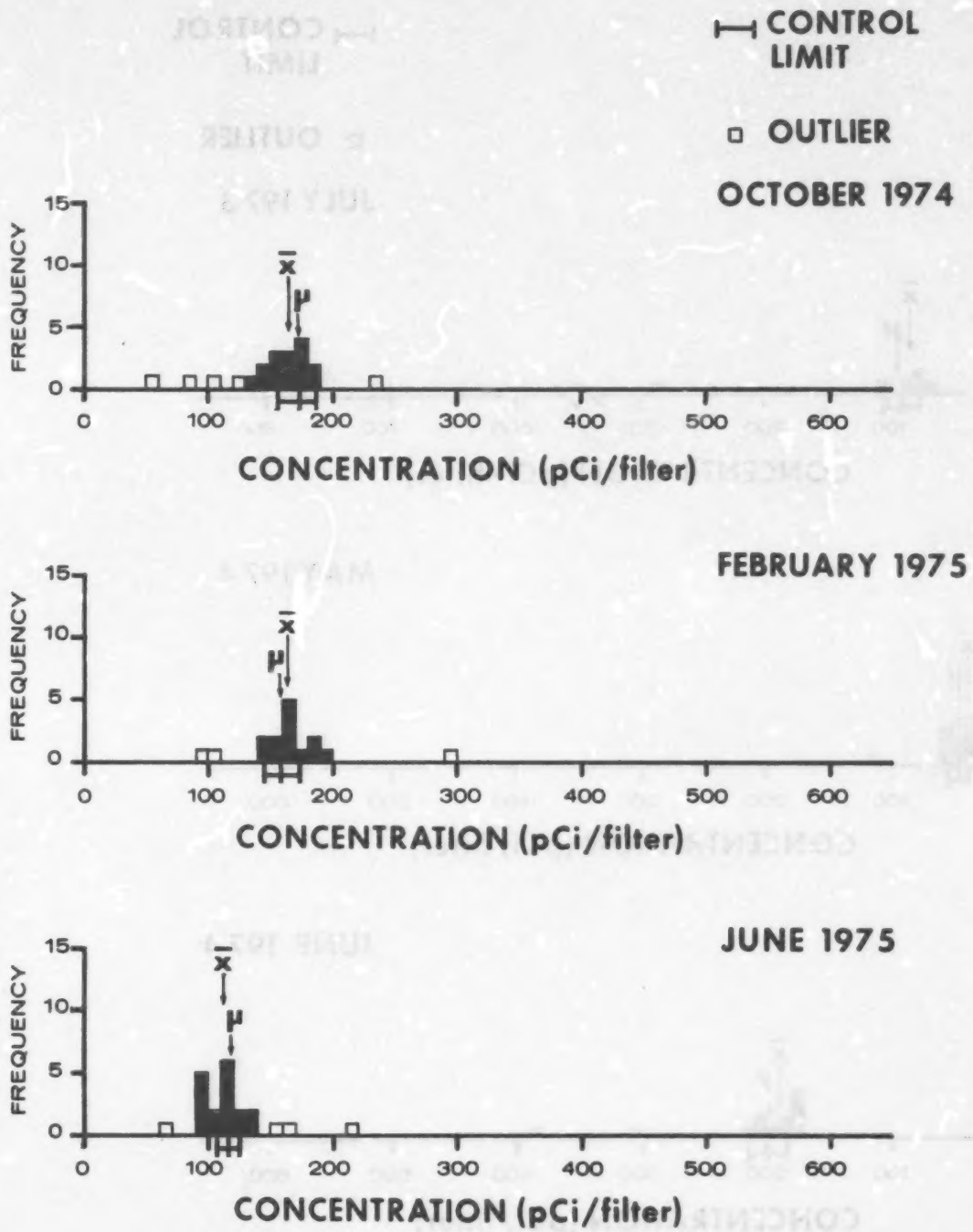


Figure 3. Histogram of Laboratory Averages Reported for Strontium-90



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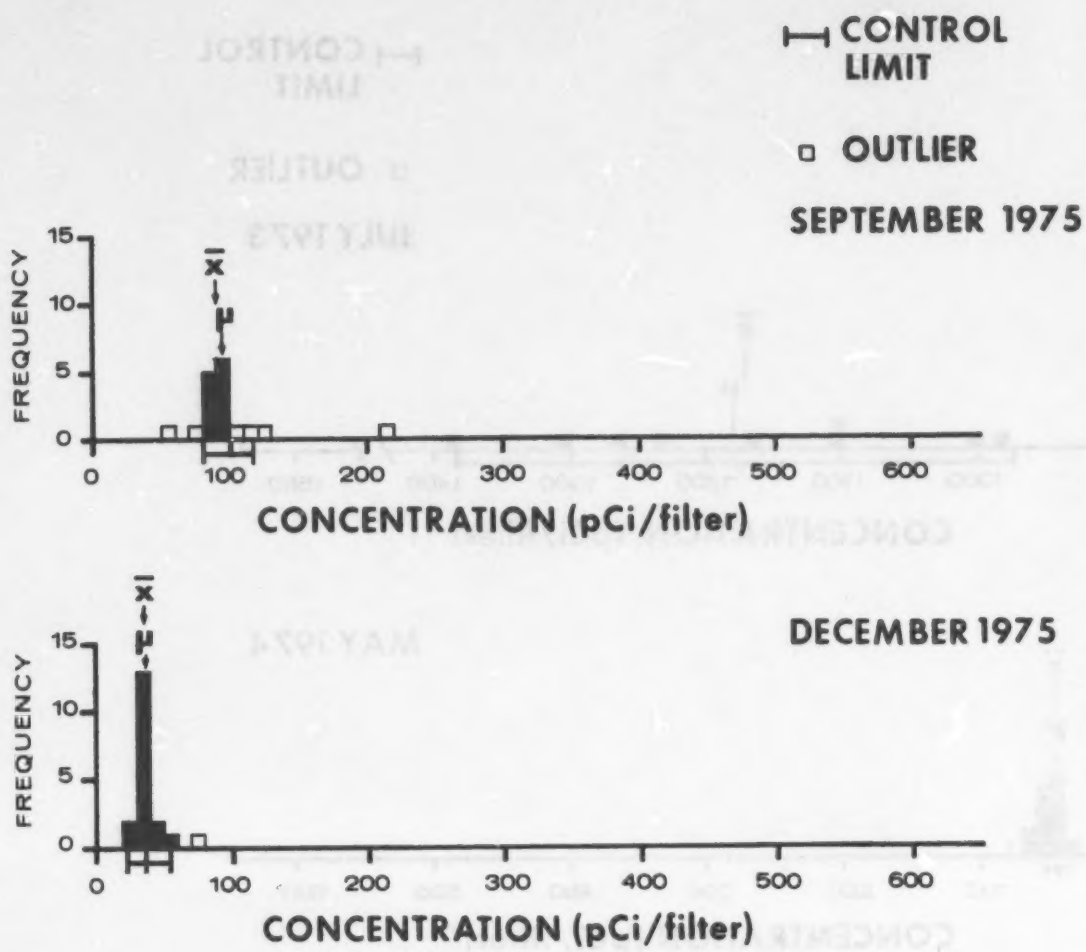

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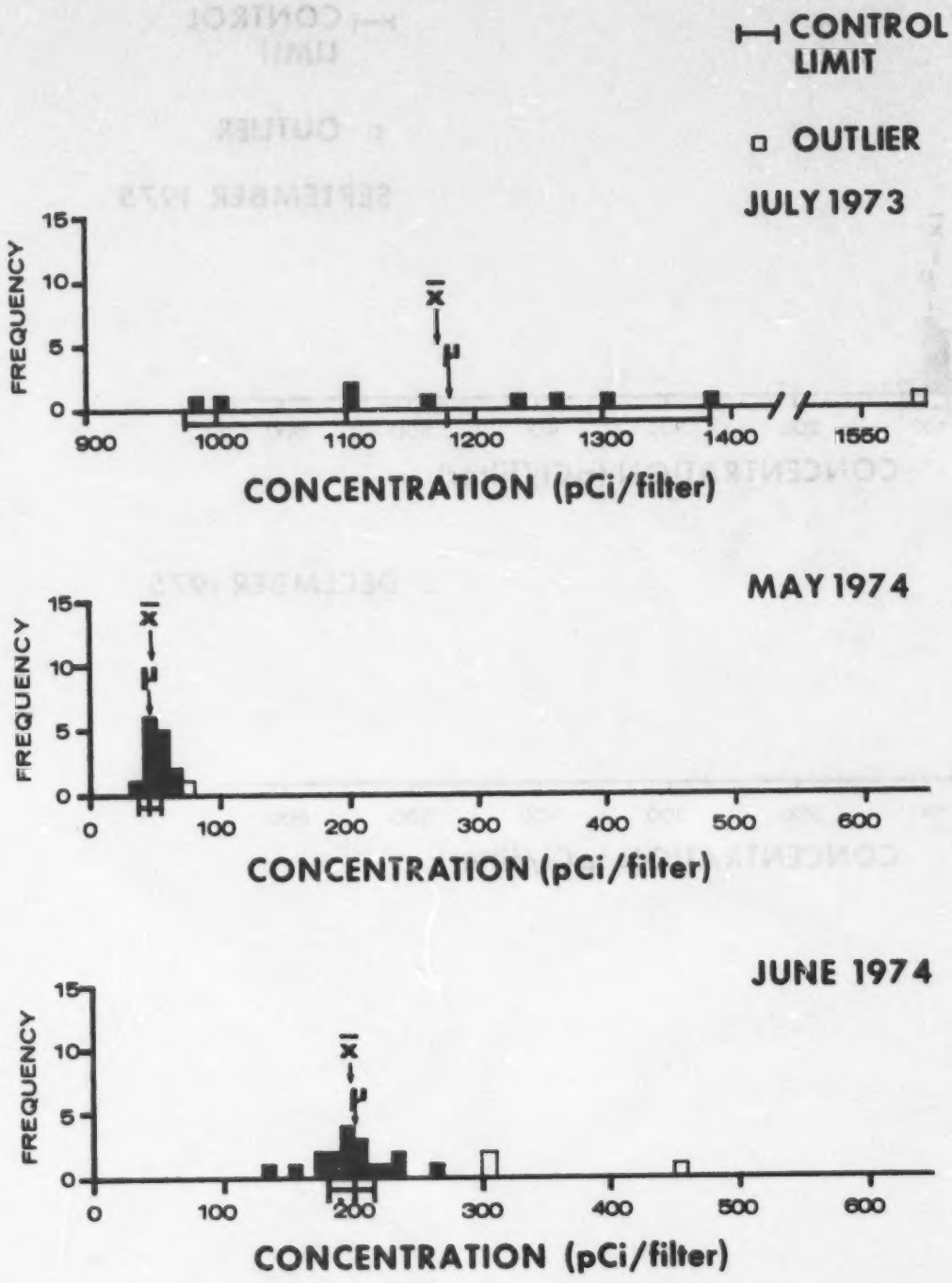
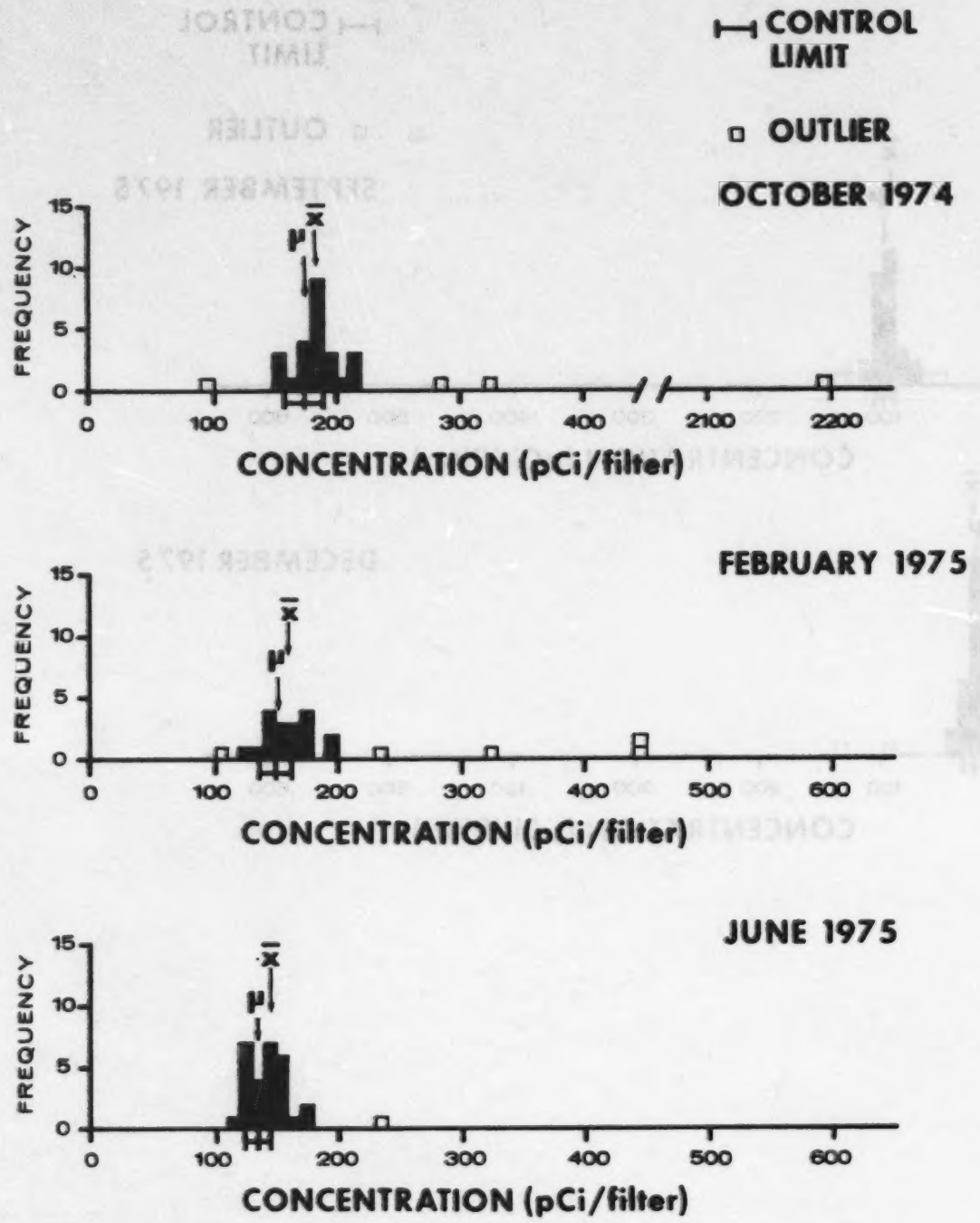


Figure 4. Histogram of Laboratory Averages Reported for Cesium-137



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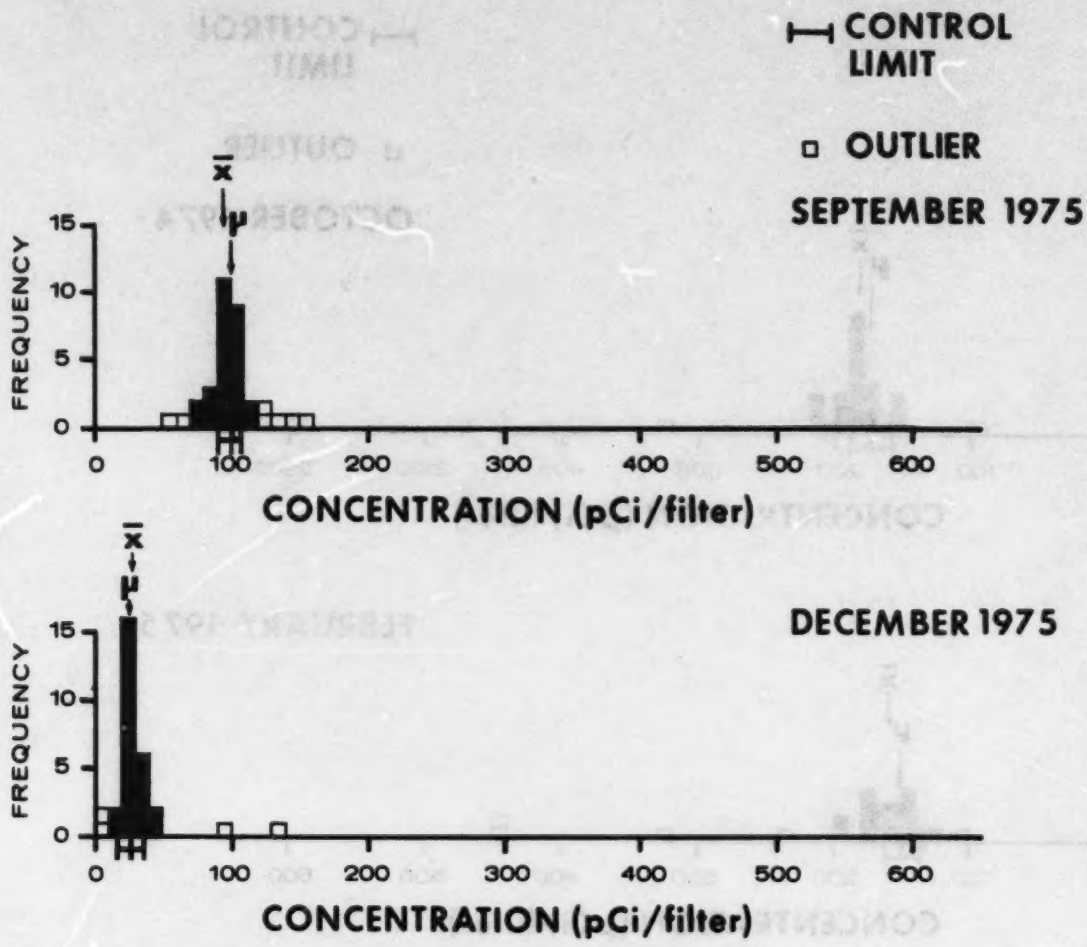

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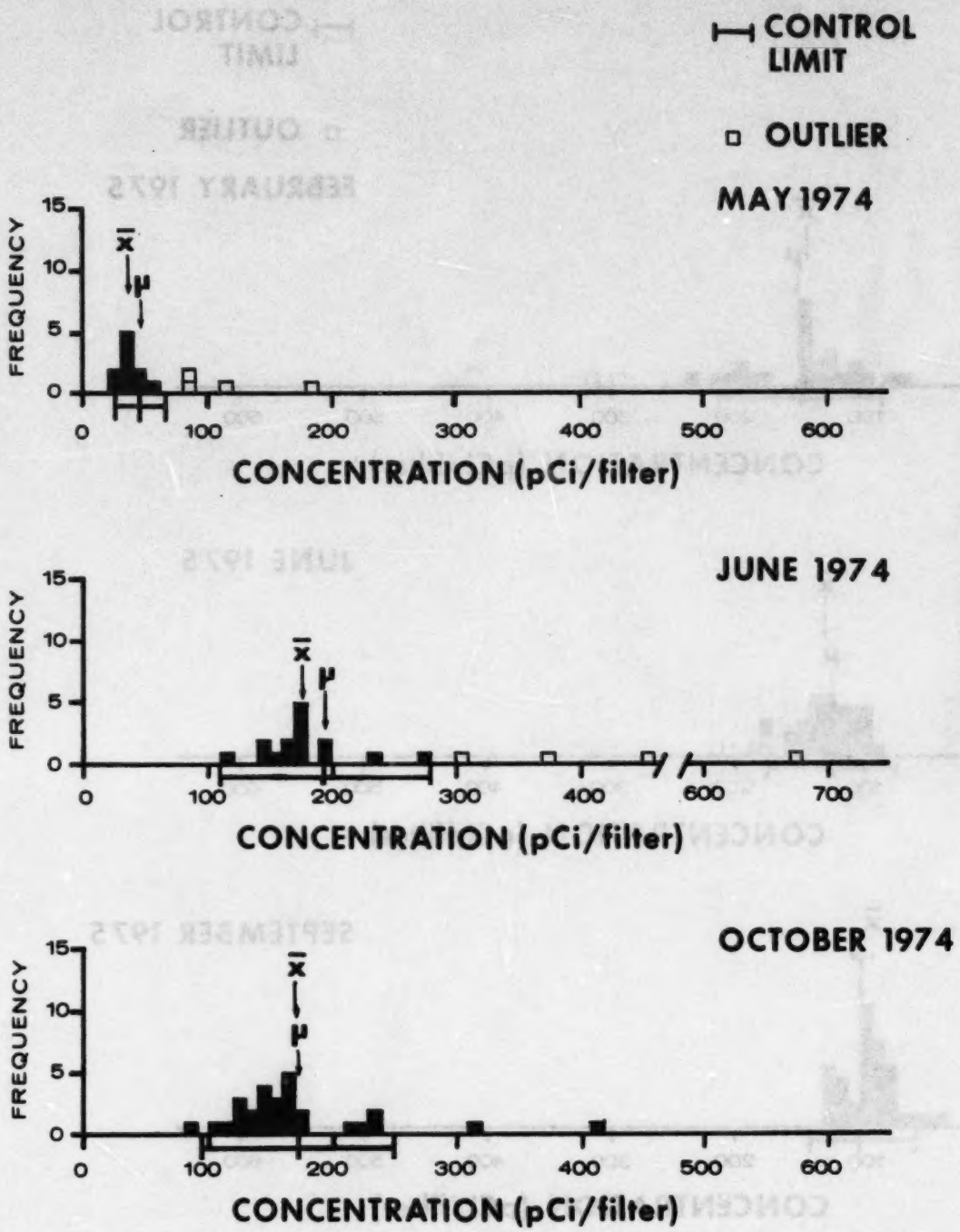
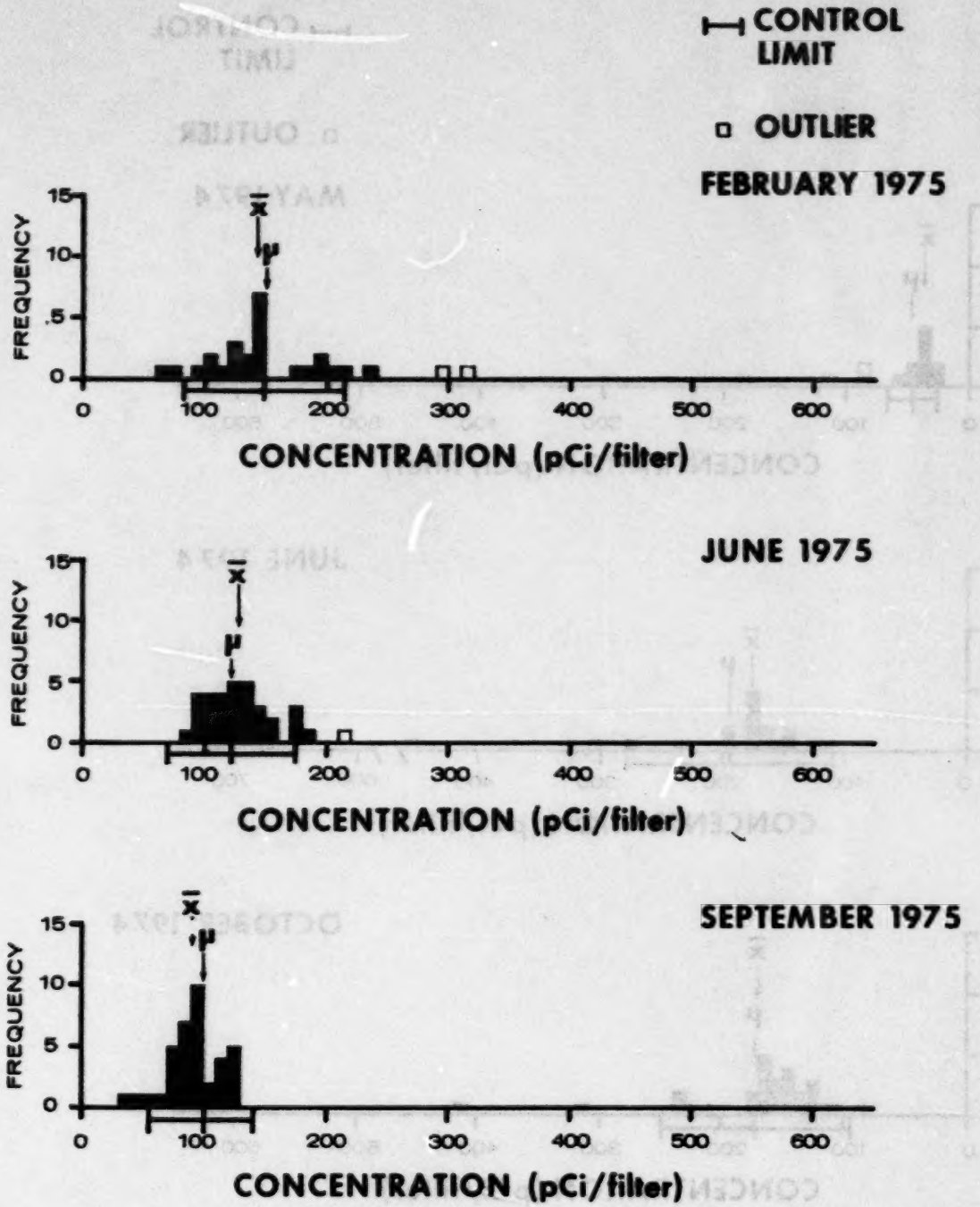


Figure 5. Histogram of Laboratory Averages Reported for Gross Alpha



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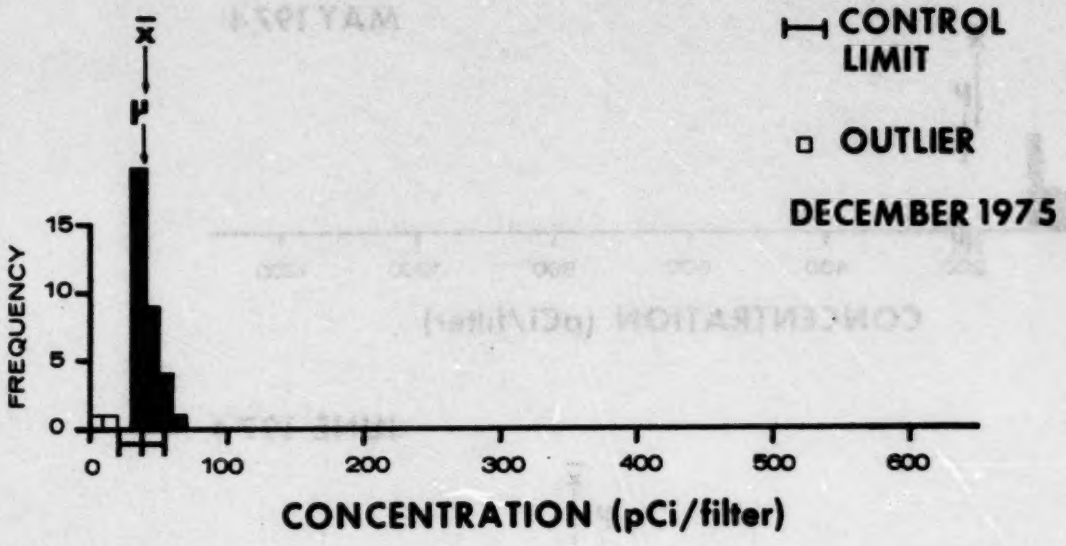

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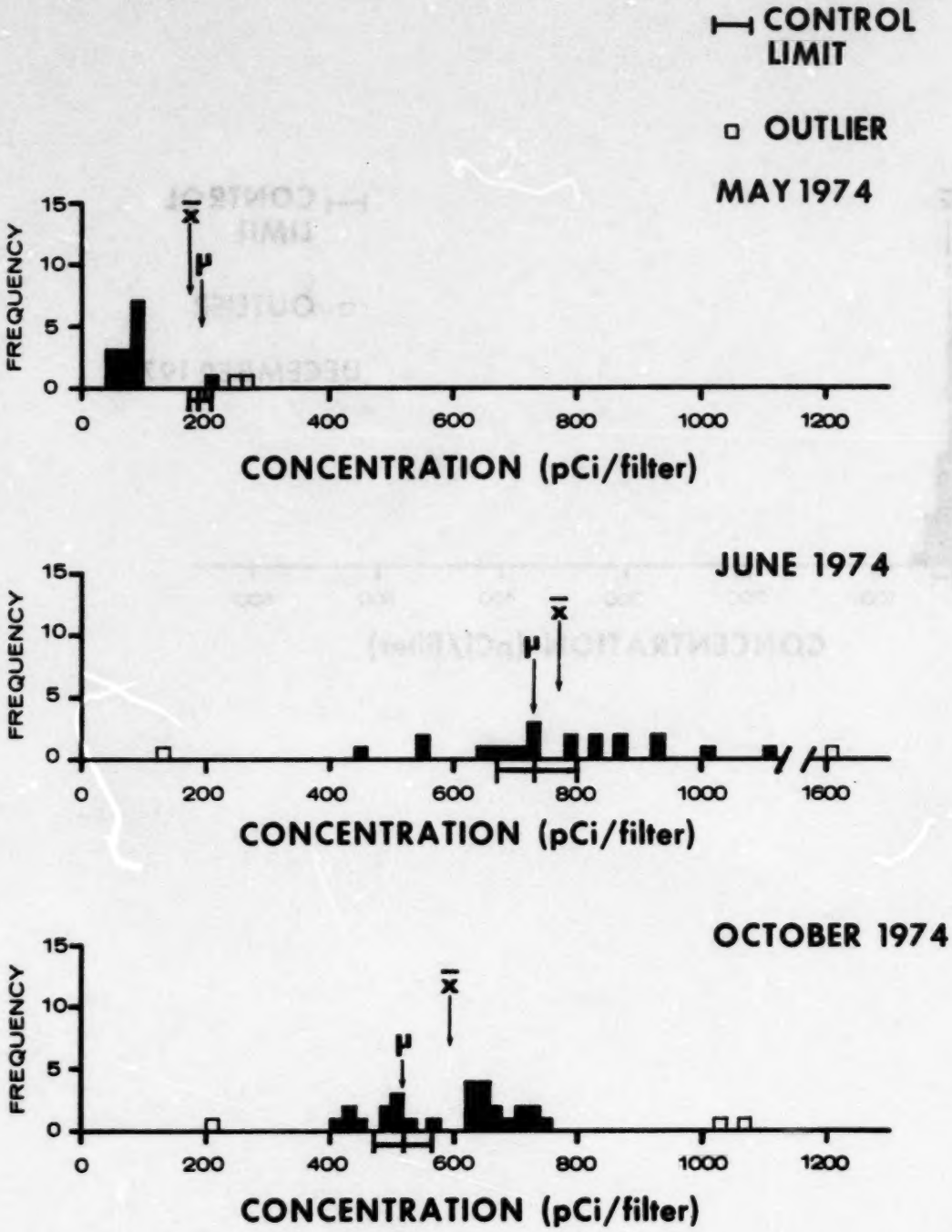

Figure 6. Histogram of Laboratory Averages Reported for Gross Beta

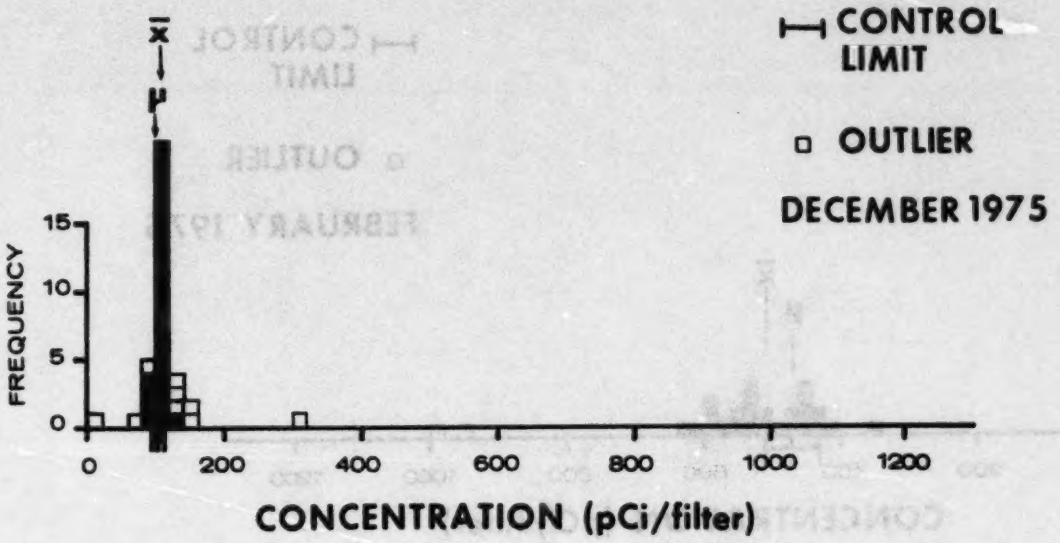

Figure 6 (continued). Histogram of Laboratory Averages Reported for Gross Beta

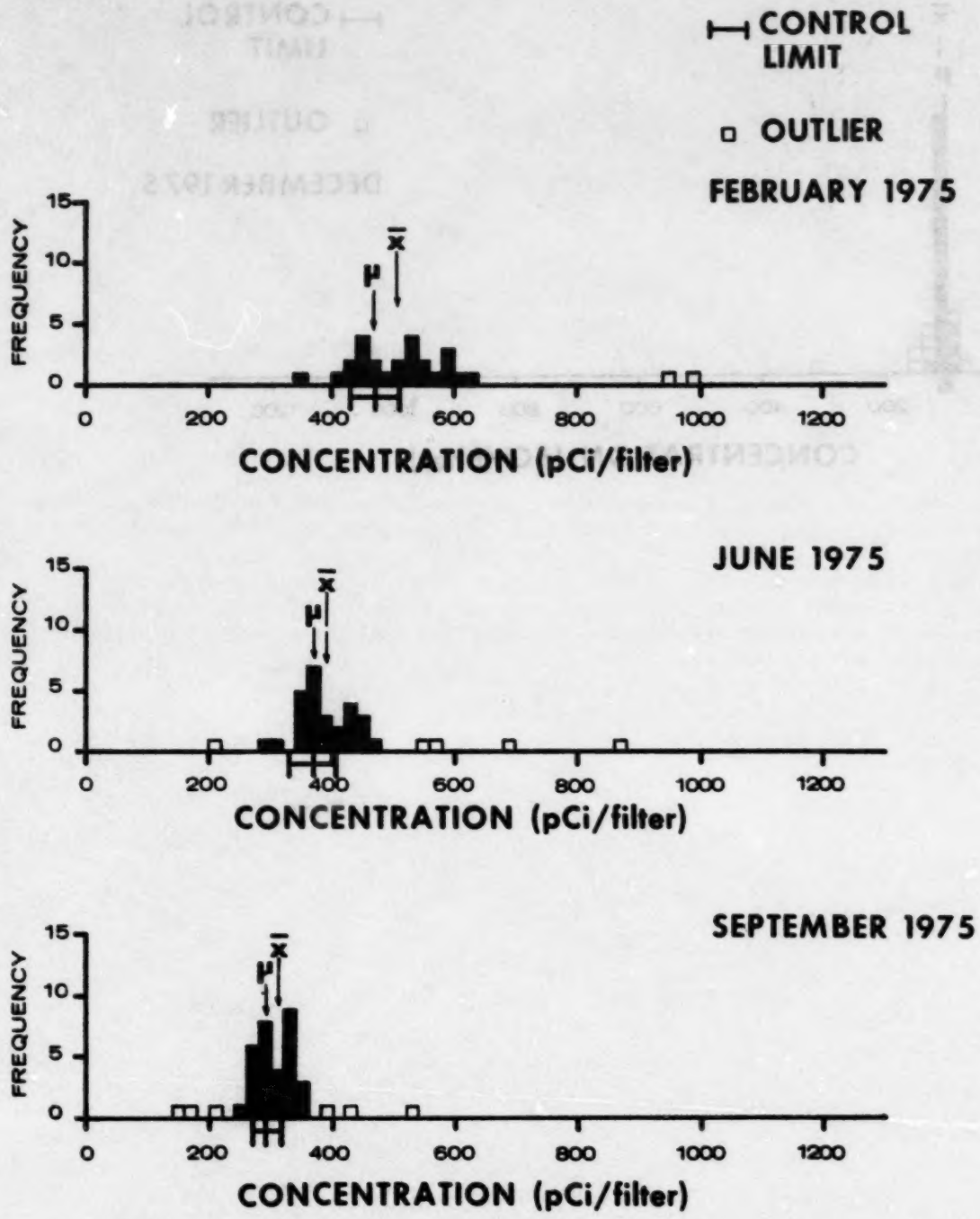

Figure 6 (continued). Histogram of Laboratory Averages Reported for Gross Beta

SUMMARY

Table 3 is a summary of the results of the analysis for the air filter cross-check samples. Using the percentage of laboratories reporting data within the 3-sigma control limits as criteria, the radionuclides are listed in the order of the ability of the laboratories to perform the radionuclide analysis. The top chart refers to the ability of the laboratories to maintain the required accuracy, while the bottom chart is a measure of the laboratories' ability to meet the precision requirements.

The conclusions drawn, of necessity, have been very general due to the limited amount of available data. The data indicate that gross alpha is the least difficult (86 percent within the control limits for accuracy and 100 percent within the control limits for precision over the 3-year period) for the laboratories to analyze. Gross beta is the most difficult to analyze (39 percent within the control limits for accuracy and 88 percent within the control limits for precision).

With the continuation of these studies, additional data will be collected and compiled. When more data become available, such parameters as control limits, methods of analysis, and instrument calibration will be critically assessed.

TABLE 3. SUMMARY OF LABORATORY PERFORMANCE
1973-75 LABORATORY INTERCOMPARISON STUDIES -
AIR FILTERS

Radionuclide Analysis	% of Laboratories within ± 3σ (99.7% Control Limits)			
	1973	1974	1975	1973-75
Gross Alpha	----	82	88	86
Cesium-137	90	53	53	55
Strontium-90	44	49	42	45
Gross Beta	----	32	42	39

Radionuclide Analysis	% of Laboratories Meeting the Expected Laboratory Precision Requirements			
	1973	1974	1975	1973-75
Gross Alpha	----	100	100	100
Gross Beta	----	96	98	97
Cesium-137	100	95	96	96
Strontium-90	86	93	85	88

APPENDIX

STATISTICAL CALCULATIONS

To illustrate the computations performed by the computer, example calculations are given using data for three samples analyzed at one laboratory (Laboratory D, see Figure 2).

The experimental data are listed and the mean, experimental sigma, and range are computed. These statistics provide measures of the central tendency and dispersion of the data.

The normalized range is computed by first finding the mean range, $\bar{R}$, the control limit, CL, and the standard error of the range, σ_R. The normalized range measures the dispersion of the data (precision) in such a form that control charts may be used. Control charts allow one to readily compare past analytical performance with present performance. In the example, the normalized range equals 0.3 which is less than 3, which is the upper warning level. The precision of the results is acceptable.

The normalized deviation is calculated by computing the deviation and the standard error of the mean, σ_m. The normalized deviation allows one to readily measure central tendency (accuracy) through the use of control charts. Trends in analytical accuracy can be determined in this manner. For this example, the normalized deviation is -0.7 which falls between +2 and -2, which are the upper and lower warning levels. The accuracy of the data is acceptable.

Finally, the experimental error of all laboratories, the grand average, and the normalized deviation from the grand average are calculated in order to ascertain the performance of all the laboratories as a group. Any bias in methodology or instrumentation may be found from these results.

EXAMPLE CALCULATIONS (Laboratory D Data, see Figure 2)

Experimental data:

Known value = μ = 3273 pCi ^{3}H/liter urine on September 24, 1974

Expected laboratory precision = σ = 357 pCi/liter

Laboratory	Sample	Result
D	x_1	3060 pCi/liter
D	x_2	3060 pCi/liter
D	x_3	3240 pCi/liter

Mean = $\bar{x}$

$$\bar{x} = \frac{\sum_{i=1}^{N} x_i}{N} = \frac{9360}{3} = 3120 \text{ pCi/liter}$$

where N = number of results = 3

Experimental sigma = s

$$s = \sqrt{\frac{\sum_{i=1}^{N} (x_i)^2 - \frac{\sum_{i=1}^{N} x_i^2}{N}}{N-1}}$$

$$s = \sqrt{\frac{(3060)^2 + (3060)^2 + (3240)^2 - \frac{(3060 + 3060 + 3240)^2}{3}}{2}}$$

= 103.9 pCi/liter

Range = r

$$r = \left| \text{maximum result} - \text{minimum result} \right|$$

$$= \left| 3240 - 3060 \right| = 180 \text{ pCi/liter}$$

Range Analysis (RNG ANLY)*

Mean range = $\bar{R}$

$\bar{R} = d_2\sigma$ where d_2* = 1.693 for N = 3

$= (1.693)(357)$

$= 604.4$ pCi/liter

Control limit = CL

$CL = \bar{R} + 3\sigma_R$

$= D_4\bar{R}$ where D_4* = 2.575 for N = 3

$= (2.575)(604.4)$

$= 1556$ pCi/liter

Standard error of the range = σ_R

$\sigma_R = (\bar{R} + 3\sigma_R - \bar{R}) \div 3$

$= (D_4\bar{R} - \bar{R}) \div 3$

$= (1556 - 604.4) \div 3$

$= 317.2$ pCi/liter

Let range = $r = w\bar{R} + x\sigma_R = 180$ pCi/liter

Define normalized range = $w + x$

for $r > \bar{R}$, $w = 1$

then $r = w\bar{R} + x\sigma_R = \bar{R} + x\sigma_R$

or $x = \dfrac{r - \bar{R}}{\sigma_R}$

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*Rosenstein, M., and A. S. Goldin, "Statistical Techniques for Quality Control of Environmental Radioassay," AQCS Report Stat-1, U.S. Department of Health, Education and Welfare, PHS, Nov 1964

therefore $w + x = 1 + x = 1 + \frac{r - \bar{R}}{\sigma_R}$

for $r \leq \bar{R}$, $x = 0$

then $r = w\bar{R} + x\sigma_R = w\bar{R}$

or $w = \frac{r}{\bar{R}}$

therefore $w + x = w + 0 = \frac{r}{\bar{R}}$

since $r < \bar{R}$ $(180 < 604.4)$

$$w + x = \frac{180}{604.4}$$

$$= 0.30$$

Normalized deviation of the mean from the known value = ND

Deviation of mean from the known value = D

$$D = \bar{x} - \mu$$

$$= 3120 - 3273$$

$$= -153 \text{ pCi/liter}$$

Standard error of the mean = σ_m

$$\sigma_m = \frac{\sigma}{\sqrt{N}}$$

$$= \frac{357}{\sqrt{3}}$$

$$= 206.1 \text{ pCi/liter}$$

$$ND = \frac{D}{\sigma_m}$$

$$= \frac{-153}{206.1}$$

$$= -0.7$$

Experimental sigma (all laboratories) = s_t (See Figure 2)

$$s_t = \sqrt{\frac{\sum_{i=1}^{N} (x_i)^2 - \frac{\sum_{i=1}^{N} x_i^2}{N}}{N-1}}$$

$$= \sqrt{\frac{162639133 - \frac{(49345)^2}{15}}{14}}$$

$$= 149 \text{ pCi/liter}$$

Grand average = GA

$$= \frac{\sum_{i=1}^{N} x_i}{N}$$

$$= \frac{49345}{15}$$

$$= 3290 \text{ pCi/liter}$$

Normalized deviation from the grand average = ND'

Deviation of the mean from the grand average = D'

$$D' = \bar{x} - GA$$

$$= 3120 - 3290$$

$$= -170 \text{ pCi/liter}$$

$$ND' = \frac{D'}{\sigma_m}$$

$$= \frac{-170}{206.1}$$

$$= -0.8$$

*U. S. GOVERNMENT PRINTING OFFICE: 1977—785-181